Ark of Inquiry: Inquiry Activities for Youth over Europe

Deliverable D1.1

Description of inquiry approach that fosters societal responsibility

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Summary

The Ark of Inquiry project aims to build a scientifically literate and responsible society through Inquiry-Based Science Education (IBSE). Ark of Inquiry will engage young European students (aged 7-18) with a broad variety of inquiry activities in order to develop their inquiry skills and raise their awareness to Responsible Research and Innovation (RRI). Both formal and informal educational stakeholders will be involved in implementing the Ark of Inquiry and in supporting students with inquiry activities. Since the core of any inquiry activity is its teaching and learning pedagogy, it is vitally important for all stakeholders to understand the pedagogical framework Ark of Inquiry uses to identify suitable inquiry activities.

This deliverable describes an initial inquiry framework for the Ark of Inquiry project. The framework itself (i.e. *Framework for Inquiry Proficiency*) shows how inquiry activities can be categorized so that a learner's inquiry capabilities (e.g. basic, advanced, expert) match the level of challenge offered by the inquiry activity. Matching a learner to an appropriate inquiry activity is required to effectively facilitate the improvement of inquiry skills and RRI awareness across a wide variety of students. This aspect will become more important later in the project when evaluation and awarding systems are designed to monitor and reward the performance and progress of students in inquiry. Finally, the *Framework for Inquiry Proficiency* clearly communicates to all stakeholders the expectations Ark of Inquiry has for developing inquiry and RRI skills across different levels of attainment. The differences between these levels and the fundamental dimensions used to categorize these levels are explained in this deliverable.

The *Framework for Inquiry Proficiency* provides a common reference point that will help maintain consistency in the development of different pillars in the Ark of Inquiry project. As the project evolves, this initial framework now presented in M6 will be continuously reviewed, and a final updated version of the framework will be presented in M24.

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1. Introduction

The Ark of Inquiry project aims to build a scientifically literate and responsible society through inquiry-based science education. The project seeks to expand young people's awareness of Responsible Research and Innovation (RRI) by disseminating across Europe engaging inquiry activities. Teachers will be trained to support students in inquiry, and with the help of cooperative communities motivate students to complete the inquiry activities. An evaluation system will be developed to provide students with meaningful feedback on their inquiry progress and a system of Inquiry Awards will reward and recognize student achievement with the inquiry activities. The widespread implementation of inquiry activities across Europe will help raise youth interest and knowledge in science, as well as persuade more European schools to adopt inquiry-based teaching methods.

In order for Ark of Inquiry to offer the best examples of inquiry activities it is essential to understand what inquiry learning is, why it is pedagogically effective and how inquiry skills and experiences are advanced through specific inquiry activities. The current deliverable provides an initial description of an inquiry approach that fosters societal responsibility. Awareness of RRI is necessary to prepare students for their future roles as informed citizens in the research and innovation process.

Defining a robust inquiry approach is crucial for establishing a foundation for the Ark of Inquiry project, and sets the stage for developing a strategy to introduce inquiry activities to students. It serves as the pedagogical centre from which subsequent tasks in the Ark of Inquiry project will be developed.

The main content of this deliverable is divided into five sections. First, there is a brief section on the importance of inquiry learning and a summary of what inquiry learning is. Second, the inquiry-based learning approach is defined in more detail. Third, the concept of RRI in the context of Ark of Inquiry is elaborated upon. Fourth, a core set of inquiry phases/skills is identified. And finally fifth, a Framework for Inquiry Proficiency is proposed. The framework is the main outcome of this deliverable and describes inquiry proficiency across three levels (A, B and C) which are used to match learners' inquiry capabilities to appropriate inquiry challenges. The framework takes into account three dimensions for progressing in inquiry: problem-solving type, learner autonomy and learner RRI awareness. The Framework for Inquiry Proficiency will serve as a cornerstone for all other deliverables in the Ark of Inquiry.

2. Content

2.1. Introduction to inquiry and inquiry learning

Inquiry is a rich term. It is used to describe *doing science* on the one hand, and *learning to do it* on the other:

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (National Research Council, 1996, p.23).

In this deliverable we use the term 'inquiry' to denote 'doing science', and 'inquiry learning' to denote 'one way to learn to do science'.

Inquiry is at the core of humanity and societal development. In its most basic sense inquiry involves some form of reflective thinking aimed at gaining insight in a problem or issue at hand, or, as Dewey (1910) defines it: 'Active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it, and the further conclusions to which it tends. [..] it is a conscious and voluntary effort to establish belief upon a firm basis of reasons' (p.6). In a narrower sense inquiry applies to the way scientists solve problems in formal scientific contexts. In this sense, inquiry is a process of reasoning scientifically and applying scientific methods aimed at analysing situations and/or datasets to reach theoretical conclusions (understanding) and/or aimed at developing practical solutions (engineering). Scientific reasoning encompasses (domain-general) reasoning skills such as the systematic exploration of problem-spaces, formulating and testing/answering questions and hypotheses, manipulation of variables and observing and drawing conclusions (cf. Bao et al., 2009). In the Ark of Inquiry project, inquiry is used in its narrower sense and refers to scientific reasoning.

The ability to reason scientifically is deemed important to learn to solve open-ended problems in the STEM domains. STEM encompasses the domains of science (physics, chemistry, biology), technology, engineering and mathematics. The report *Science Education Now; A renewed pedagogy for the future of Europe* (Rocard, Csermely, Jorde, Lenzen, Walberg-Henrikson & Hemmo, 2007) offers a summary of what inquiry is and why it is needed in Europe. Europe's long term capacity to innovate and tackle new challenges requires scientifically informed citizens who participate actively in today's knowledge based society. Prosperity depends on turning innovative ideas into products and services that create growth and jobs. In addition, responding to modern challenges in the 21st century requires citizens who can reason scientifically and evaluate the societal impact of complex new technologies.

Unfortunately, a lack of interest towards science among many young people puts Europe's future prosperity at risk. The *Science Education Now* report specifically blames the traditional way science is taught in schools as the main reason for this problem, and recommends implementing inquiry-based teaching methods to renew young people's interest in science. Research confirms that learning to inquire and reason scientifically might best be done by inquiry learning in which learners experience what it is to do science and solve problems by scientific reasoning (Bao et al., 2009). Traditional formal science education emphasizes a 'top-down transmission' approach where a teacher lectures about abstract concepts, deduces implications and then gives examples of applications. This approach treats the teacher as an authoritative source of information whose role is to directly transmit predefined knowledge to students who receive and absorb this accumulated knowledge. In this situation students quickly discover that knowing the right answer is far more important than asking thoughtful questions. Hence, there is a tendency for students to rely on memorization rather than on understanding. Consequently, for many students science education is perceived to be difficult and irrelevant. In contrast, inquiry-based science education relies on a 'bottom-up' approach where learners first experience relevant problems, are curious to search for solutions to these problems, willingly experiment and tolerate failure to find answers, and are guided to cumulatively construct a deeper understanding of scientific concepts. As emphasized in the *Science Education Now* report, inquiry learning has proven to be effective in stimulating interest in science. If implemented more widely, inquiry-based methods promise to equip future researchers and other societal actors with the necessary knowledge and tools to fully participate and take responsibility in the research and innovation process.

2.2. Defining inquiry learning

The inquiry-based learning approach developed gradually out of several important traditions in the history of education. In the early 20th century John Dewey criticized the rote memorization of facts and formulas in science education, and attached great importance to applying a scientific methodology to solve problems (Dewey, 1938). In the field of psychology Jean Piaget and Lev Vygotsky were influential in drawing attention to the importance of learners' constructing knowledge from their experiences. Jerome Bruner pointed out that student learning in schools could be either active or passive, and advocated for discovery learning as an active approach to facilitate retaining knowledge in the long-term (Bruner, 1961).

In recent times there has been a push to engage students in experiences with how science is actually done. Bybee and Van Scotter (2007) argue that to understand science, students need to do science. Accordingly, inquiry learning is strongly characterized by teaching processes that play a central role in the work of practicing scientists (Edelson, Gordis & Pea, 1999; Madhuri, Kantamreddi & Prakash Goteti, 2012; Kolloffel, Eysink & de Jong, 2011; Chang & Wang, 2009; Chang, Sung & Lee, 2003; Keselman, 2003). In a publication by the US National Science Foundation, inquiry [learning] was defined as

> an approach to learning that involves a process of exploring the natural or material world, and that leads to asking questions, making discoveries, and rigorously testing those discoveries in the search for new understanding. Inquiry, as it relates to science education, should mirror as closely as possible the enterprise of doing real science (National Science Foundation, 2000, p. 2).

But inquiry learning can be challenging and at times difficult for students. According to de Jong (2006), "Students have difficulty choosing the right variables to work with, they find it difficult to state testable hypotheses, and they do not necessarily draw the correct conclusions from experiments" (p. 352). For inquiry learning to be productive (i.e. correct and successful according to scientific reasoning and methodology) it requires pedagogical support. Furthermore, for many teachers the inquiry learning approach appears to be complex, suitable mainly for high-ability students, and they feel inadequately prepared (Colburn, 2000). A degree of simplification seems to be needed to make teachers feel more confident in organizing and implementing inquiry activities in daily school practices regularly.

2.3. Defining Responsible Research and Innovation

Responsible Research and Innovation (RRI) has been defined as an inclusive approach that allows

> all societal actors (researchers, citizens, policy makers, business, third sector organisations etc.) to work together during the whole research and innovation process in order to better align both the process and its outcomes with the values, needs and expectations of European society (Science with and for Society, 2014).

Citizens in democratic societies should be involved in decisions regarding new technologies when cultural, environmental, social, economic or ethical values are at stake. Preparing citizens to engage constructively in discussions about whether a new technology is beneficial or harmful to society requires providing them with a basic understanding of how to evaluate scientific research and innovation. Thoughtful and informed thinking comes from making judgments about the credibility of different types of evidence. Citizens need to be skilled in asking critical questions, evaluating qualitative and quantitative data, and discussing RRI issues with a variety of societal actors. Discussing science policy issues with a variety of stakeholders ensures that citizens are exposed to information from different perspectives. Likewise, interacting with a diversity of stakeholders increases the likelihood that persons in positions of authority feel a sense of responsibility to carefully consider socio-scientific issues. A greater involvement of informed citizens in the research and innovation process fosters inclusive and sustainable outcomes that ensure public trust in the scientific and technological enterprise. Although RRI is related to and relevant for all scientific domains, it has been argued that especially in the STEM domains in which emerging technologies encounter ethical questions and choices, RRI awareness is important (e.g. Sutcliffe, 2011).

The Ark of Inquiry project will promote RRI by teaching students core inquiry skills needed to evaluate the credibility and consequences of scientific research and by offering opportunities for students to engage with different societal actors involved in the research and innovation process. It is important that students experience inquiry activities outside of the formal educational setting and become aware of the broader community of people involved in research and innovation. Students who have an early opportunity to interact with a broad audience of stakeholders will be better prepared later as citizens to debate and think about scientific issues with an open and critical mind considering what have been mentioned as typical RRI aspects such as the global and sustainable impact of research findings and innovations in which positive and negative consequences are balanced, societal relevance, and the importance of participatory design and co-creation with end users (Sutcliffe, 2011). Communicating and sharing ideas develops awareness and understanding among all participants. Preparing future citizens for their role as active and informed participants in RRI therefore requires emphasizing the importance of communication and dialogue. In the Ark of Inquiry project this aspect is highlighted by including inquiry activities where students must interact with a range of stakeholders such as science centre staff, university researchers, teacher education students, and citizens/end users. For instance, students can be asked to write about inquiry activities and outcomes as journalists of science, hence seeking debate with others about research findings.

Discussing, communicating and collaborating with a broad audience of stakeholders about scientific topics can also help engage more girls in science. It is known that context may influence interest in a particular science content area. For example, boys tend to be interested more in contexts that are technical, mechanical, or explosive; whereas girls prefer contexts such as health and medicine, beauty and the human body, ethics, aesthetics (Sjøberg& Schreiner, 2010). Inquiry activities that engage students with a range of stakeholders increase the likelihood that girls can connect learning about a scientific topic to a personally relevant context, and consequently promises to attract more interest from girls to pursue careers in science and technology.

2.4. Inquiry phases

Sharing engaging inquiry activities across Europe and providing learners with meaningful feedback to improve their inquiry proficiency are major aims of the Ark of Inquiry project. It is thus necessary to define what exactly constitutes an inquiry activity and how inquiry proficiency is advanced through inquiry learning activities. Processes such as asking questions, making predictions and conducting experiments are all part of inquiry and inquiry learning. But to arrive at a systematic understanding of inquiry (learning) activities, we relied on a recent review of inquiry (learning) phases (Pedaste et al., submitted). Pedaste et al. rigorously reviewed over 100 different terms found in contemporary educational literature describing inquiry processes (e.g. observe, identify the problem, predict, investigate, find patterns, analyse, organize the data, draw conclusions, discuss, reflect, etc.). The authors then synthesized an inquiry learning cycle framework to highlight which activities are conceptually distinct and fundamental to inquiry. They found that there are five distinct inquiry phases (Orientation, Conceptualisation, Investigation, Conclusion, and Discussion) and seven sub-phases (Questioning, Hypothesis Generation, Exploration, Experimentation, Data Interpretation, Reflection, and Communication) that constitute the core features of inquiry and hence inquiry learning. Figure 1 shows how Pedaste et al. organized the connections between the different phases.

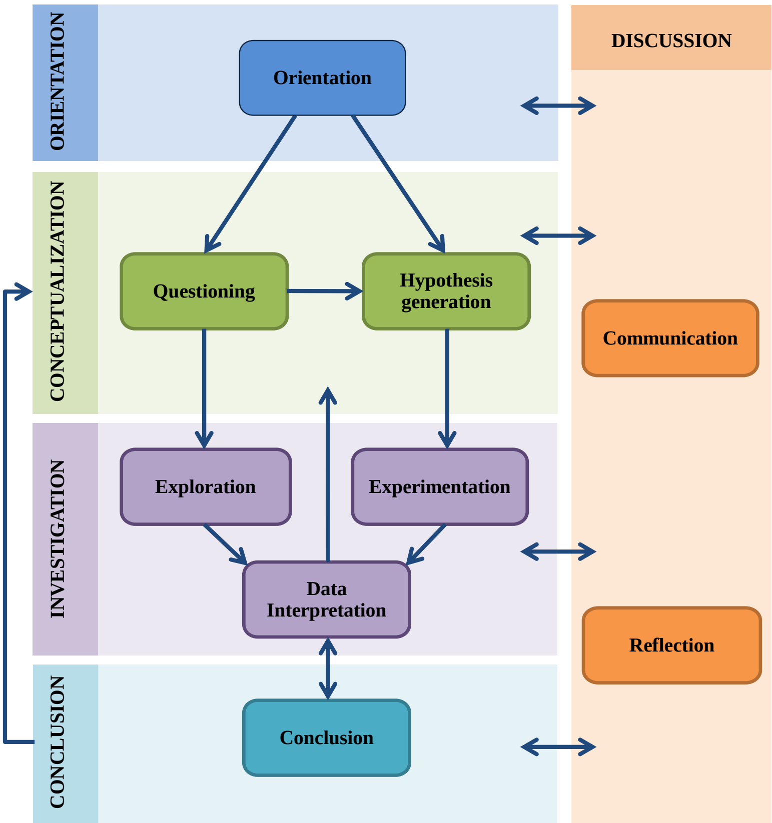


Figure 1. Inquiry learning framework [from Pedaste et al. (submitted)].

As shown in Figure 1, inquiry begins with the Orientation phase, which is a process to stimulate curiosity about a topic and leads to a problem statement. The next phase is Conceptualisation, where either research questions or hypotheses are stated. Then comes the Investigation phase, which is a process of gathering empirical evidence to resolve the research question or hypotheses. Finally there is the Conclusion phase, where research findings from the inquiry are reported and justified by the results of the investigation. Another inquiry phase, the Discussion phase is unique because it is inconstant connection to all the other phases. It consists of communicating partial or completed outcomes, as well as reflective processes to regulate the learning process.

In terms of pathways through which inquiry unfolds, Figure 1 shows that inquiry is rarely a simple linear sequence. Various possible pathways exist and are indeed expected. Inquiry begins in the Orientation phase, but already in the next phase there is a choice to move through either the Questioning or Hypothesis Generation sub-phase. The difference relates to how familiar students are with the theory that underlies a topic. If students have little to no background then they should start with the Questioning sub-phase (which subsequently guides them to the Investigation phase via the Exploration and Data Interpretation sub-phases). After acquiring experience with the topic the students can return and select the Hypothesis Generation sub-phase. Alternatively, students with no familiarity with a topic could move from the Questioning to Hypothesis Generation sub-phase if they collect enough background information to formulate a specific hypothesis. In any case, Hypothesis Generation is an important phase because it leads to the Experimentation sub-phase. Experiments usually form the most critical part of inquiry since it is through empirical testing that relationships between dependent and independent variables can be established. After the Investigation phase there is the Conclusion phase. A unique feature of the Pedaste et al. framework is that the Discussion phase is in continual connection with the other inquiry phases. The Discussion phase allows for communication and reflection at any time during inquiry.

The main result of the Pedaste et al. review paper with respect to the Ark of Inquiry project is a structured way to conceptualize inquiry activities. Each inquiry phase in Pedaste et al. identifies sub-processes that are characteristic of inquiry activities. Furthermore, what is expressed by the arrows in the figure is the cyclic nature of inquiry in which questions lead to answers which in turn lead to new questions and so on. In principle, it is a never-ending endeavour in which the Discussion phase runs along all the other phases further strengthening its cyclic nature: in each phase critical and open discussion of (the outcomes of) the inquiry activity may lead to a restart.

Nevertheless, in the Ark of Inquiry project we not only need to identify the core processes that constitute high-quality inquiry activities, but also categorize inquiry activities according to progress levels. The next section describes how proficiency in inquiry proceeds.

2.5. Framework for Inquiry Proficiency

In the Ark of Inquiry we need a system to describe inquiry proficiency ('productive inquiry') across different levels. Because the anticipated users of the Ark of Inquiry include a wide variety of students, it is necessary to match a learner's inquiry capabilities to a suitably challenging inquiry activity. A useful starting point for creating a system of proficiency levels is the Common European Framework of Reference for Languages (2001). This internationally recognized system provides 'can do' descriptors to help learners self-assess their level of proficiency and divides language learners into three broad levels (A, B, and C), corresponding respectively to basic speaker, independent speaker and proficient speaker. The main dimension that determines proficiency is how well a speaker can achieve everyday goals. In a similar way, a system for inquiry proficiency was developed to distinguish three inquiry levels: A (basic inquiry), B (advanced inquiry) and C (expert inquiry). These three levels categorize inquiry activities according to how well they challenge a learner to exhibit inquiry behaviour.

In our system, the degree of challenge presented by an inquiry activity is determined by three dimensions: problem-solving type, learner autonomy, and learner awareness of Responsible Research and Innovation. The type of problem to be solved or question to be answered in an inquiry activity can be divided into two different types: well-defined or ill-defined. A well-defined problem has a clear path from which to reach a solution and the solution itself has been thoroughly established as a scientific fact. On the other hand, an ill-defined problem does not suggest an obvious path to reach a solution and a 'correct' solution is not necessarily prescribed beforehand. Progress in inquiry activities should move from well-defined to ill-defined problems in order to challenge inquiry learners.

The second dimension used to characterize progress in inquiry activities is the degree of learner autonomy. Initially, inquiry is initiated and led by the teacher and/or by the materials (for instance computer-based platforms that provide structural scaffolding), so that students become familiar with the method. However, even at this initial level students are not given the results directly, but are supported to engage in inquiry processes to discover and understand what they are doing and learning. As inquiry learners progress, a teacher guides the process less and less and instead begins to provide the learner with professional feedback on the outcomes of different inquiry processes. The student moves from structured inquiry to guided inquiry to finally open inquiry (cf. Colburn, 2000). Thus progress in inquiry is characterized by learning that proceeds from teacher-initiated to student-led. This progression is associated with self-regulated learning, where learners take control of and direct the learning process for themselves. Other researchers have pointed out the gradual difference in the forms of inquiry learning (Banchi & Bell, 2008).

The third dimension used to characterize inquiry activity progress is learner awareness of Responsible Research and Innovation (RRI). Inquiry activities should gradually expand the amount and type of interaction students have with important stakeholders in the research and innovation process in order to include different perspectives. For example, basic inquiry activities might take place within the school setting involving only a teacher and fellow students, but progression in inquiry requires gradually expanding the scope of societal stakeholders a learner interacts with, for instance off-school premises work visits or through social media platforms. RRI can also encompass the responsibility to apply research and research findings in a balanced and respectful way in relation to the three pillars of sustainability: People, Planet and Profit (Slaper & Hall, 2011). A developed sense of RRI allows a learner to communicate the relevance of research and research findings to people and society.

Based on the above dimensions for characterizing progress in inquiry activities (problem-solving type, learner autonomy and learner awareness of RRI), a Framework for Inquiry Proficiency (Table 1) was created to relate those dimensions of progress to the inquiry phases described in Section 2.4. The Framework for Inquiry Proficiency shows how different inquiry and RRI skills vary across proficiency levels. Table 1 gives a general description of the three proficiency levels. Further operationalization of the three levels will be worked out in the evaluation system (D1.2) which will describe the stepping stones and indicators of each phase at each level.

Table 1. Framework for Inquiry Proficiency

INQUIRY PHASE	INQUIRY PROFICIENCY LEVEL		
	A (basic inquiry)	B (advanced inquiry)	C (expert inquiry)
ORIENTATION	Students are introduced to a problem within a well-defined problem space	Students are introduced to a problem in a semi-structured problem space	Students identify a suitable problem in an open-ended problem space
CONCEPTUALISATION	Students are led to common questions and/or hypotheses that will be studied in the investigation	Students formulate questions and/or hypotheses through guidance	Students explore and formulate meaningful questions and hypotheses
INVESTIGATION	Students collect and analyse data according to prescribed procedures and fixed instruments	Students collect and analyse data in semi-structured steps and formats	Students operationalize procedures and formats through which they collect and analyse data
CONCLUSION	Students reach an understanding of fixed conclusions	Students reach conclusions through (semi-)structured procedures	Students reach conclusions and explain the process
DISCUSSION	Students present in fixed formats to teachers and/or peers	Students present and communicate in semi-structured or self-chosen formats to teachers and/or peers	Students present and discuss at appropriate times and in applicable formats with diverse stakeholders

In practice, it might be the case that within the entire inquiry activity which is rated at one of the three levels, sub-phases of the activity could deviate from that level and be labelled otherwise. For instance, an overall open inquiry (C-level) might have set relatively fixed formats for the conclusion and discussion phase (B-level). Deliverable 2.1 on the selection and description criteria of inquiry activities will elaborate on the way in which the overall level and levels of particular sub-phases are communicated in the Ark of Inquiry. Also, the general aim of the Ark of Inquiry is to engage students in inquiry learning by allowing them to start at the proficiency level they are currently at, and then helping them progress further. However, students not only develop inquiry skills. At the same time, they learn about scientific content (factual and conceptual knowledge and understanding) in the STEM domains. This means that students with an inquiry proficiency level at C can still do learning activities at the A-level to develop their content knowledge. Hence, the Ark of Inquiry seeks to provide a learning environment that targets both understanding of scientific content as well as the development of scientific reasoning skills (cf. Bao et al., 2009). Deliverable 1.2 on the evaluation system will address this issue. However, based on this general Framework for Inquiry Proficiency, inquiry activities at the three levels can be described. An indication of inquiry activities at the three levels is given below.

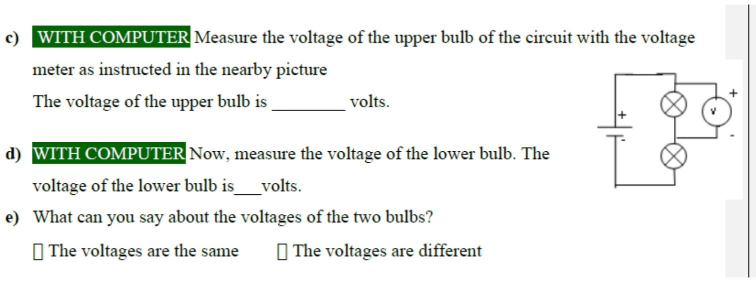
A-level (basic inquiry)

At the A-level, inquiry activities have a predefined outcome known to the teacher and/or prescribed by the learning materials. Inquiry at the A-level is aimed at teaching learners how to engage in and conduct inquiry. Students learn to report and present their findings according to a worksheet or fixed presentation format. In Box 1 an example of an A-level inquiry activity is described.

Box 1 – Example of an A-level inquiry activity

Learning about electricity circuits with a simulation

Pairs of students work with a simulation to learn about electrical circuits. The students are provided with worksheets that guide their investigations (structured inquiry). The sequence of the worksheets and the build-up of each worksheet predefine the inquiry path that the students follow during the activity. The worksheets introduce notions related to electricity circuits, starting with the distinction between open and closed circuits, the effect of adding more components (e.g. light bulbs) in series on the voltage across the components (and/or brightness of bulbs), the effect of adding more components (e.g. light bulbs) in parallel on the voltage across the components (and/or brightness of bulbs), and the difference between series and parallel circuits. Individual worksheets aim at activating prior knowledge, and provide the students with well-defined activities (build circuits, observe brightness, measure voltages), and predefined questions (gradually becoming a bit more open) that guide the interpretation of the activities. As they are working in pairs, students are expected to communicate to each other, and through filling the worksheets with the educator, but there is no wider audience addressed yet.


c) WITH COMPUTER Measure the voltage of the upper bulb of the circuit with the voltage meter as instructed in the nearby picture
The voltage of the upper bulb is ________ volts.

d) WITH COMPUTER Now, measure the voltage of the lower bulb. The voltage of the lower bulb is___volts.

e) What can you say about the voltages of the two bulbs?
☐ The voltages are the same ☐ The voltages are different

Sample of a worksheet

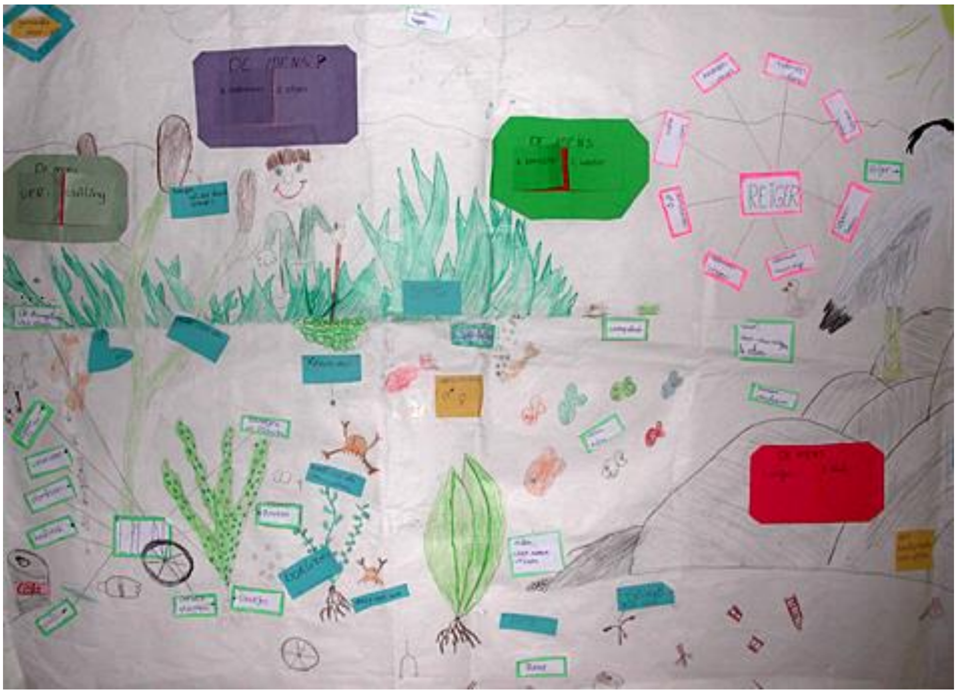
B-level (advanced inquiry)

At the B-level, inquiry activities take place in a predefined problem space that sets limits to the research; however the problem itself is ill-defined. The main goal here is to teach learners to think about what to investigate and guide them towards independency related to knowing how to inquire. The process of inquiry is partly scaffolded. Findings are communicated in semi-structured or self-chosen formats to teachers and/or peers. In Box 2 an example of a B-level inquiry activity is described.

Box 2 – Example of a B-level inquiry activity

Designing an ecosystem

Small groups of students are provided with a design problem (design an ecosystem), and four design questions (semi-structured inquiry). The first question (who am I) makes them choose a central inhabitant of the ecosystem (e.g.a rabbit). The second question (what do I need to do) asks them to define actions the inhabitant undertakes to survive in the ecosystem (e.g. eat, drink, mate, flee). The third question (what do I need myself to complete that action) makes them design parts of the rabbit (e.g. mouth, ears, legs, etc.). The fourth question (what do I need in my environment to complete that action) makes them design things and other inhabitants in the environment (e.g. carrots, water, female rabbits, hiding places). Then the cycle of questioning restarts to design the carrot, the female rabbit, parts of the hiding place, and so on. The children choose their own presentation format and are only provided with materials. They present their findings to their peers in the classroom as well as through social media to peers at other schools. In their presentations, the students reflect on their growing knowledge of ecosystems, as well as on their collaborative process of inquiry. The groups are invited to think through the impact of human presence in ecosystems.



Example of a design product: Ecosystem of a fish

C-level (expert inquiry)

At the C-level students undertake an open research activity in an ill-defined problem space or in a complex societal context. Students are provided with materials and/or a problem area without any specific instruction as to what to investigate and how to approach the problem. The students might start to work in a multidisciplinary team to get a real view on the problem area and possible solutions. Twenty-first century skills such as innovative and creative thinking might be needed to come to the right solution and explore new possibilities. The students learn when to inquire and how to reflect, as well as discuss outcomes in collaboration with diverse stakeholders. In Box 3 an example of a C-level inquiry activity is described.

Box 3 – Example of a C-level inquiry activity

How catchy..: What is in the net?

A large and still growing database on fish caught in the Dutch Wadden Sea sets the stage for an open inquiry into the history and recent developments of its fish population. The Wadden Sea has been monitoring its fish population for over 50 years now, and they have developed a large database on their structural observations.
Students can enter the website and investigate the database. But with what question? First, they have to think about the problem they want to investigate. For instance, they can generate questions on the biodiversity in the Wadden Sea, the decline or rise of specific fish populations, or investigate the impact of events such as climate changes or human interventions.
The students will have to explore the database to get a grasp on what kind of data is present and how they could suit their investigations (open inquiry). Maybe they have to plan an extra collection of data near the Wadden Sea or need to make a comparison with other small seas over the world. The students present and discuss their findings with the organisation and write a short article for the local newspaper on what they found out.

Snapshot of the Wadden Sea database (www.waddenzeevismonitor.nl)

3. Conclusions

This deliverable presented an inquiry approach for the Ark of Inquiry project that fosters societal responsibility. The approach is concisely illustrated in Table 1, where a Framework for Inquiry Proficiency is shown. To arrive at this framework we relied on a recent review article of inquiry (learning) phases by Pedaste et al. (submitted), who found that there are five inquiry phases (Orientation, Conceptualisation, Investigation, Conclusion and Discussion) that constitute the core features of inquiry. The Framework for Inquiry Proficiency shows how the inquiry phases are related to three levels of proficiency (basic, advanced and expert inquiry). The levels of proficiency were created based on taking into account three dimensions: (1) problem-solving type (progressing from well- to ill-defined problems), (2) learner autonomy (progressing from teacher/material-led to student-led processes), and (3) RRI awareness (progressing from sharing with a small audience to discussions and interactions with a broad audience of stakeholders).

The RRI aspect in this framework develops during the whole inquiry process since discussion takes part in and alongside each phase of inquiry (see Figure 1 in this deliverable). The end goal is to prepare students to engage constructively in socio-scientific discussions. Advancing them towards open-ended inquiry problems and self-directed learning allows students to explore personally relevant topics, postulate meaningful research questions/hypotheses, evaluate empirical evidence gathered from experiments and make scientifically justified conclusions. All these inquiry skills are needed for citizens to critically evaluate new research and innovation when cultural, environmental, social, economic or ethical values are at stake. Moreover, advancing students towards greater RRI awareness in terms of interacting with diverse stakeholders is important because it prepares them to consider new perspectives, keep themselves informed about new developments in science and technology, and share their ideas through open dialogue.

The Framework for Inquiry Proficiency will be fine-tuned and tested in the next few months. Several practical issues will need to be addressed to further tailor the framework to the inquiry activities collected in the Ark. The general framework presented here serves as the pedagogical foundation that all other deliverables can build upon in order to reach the goals of the project. It forms the starting point for assessing and awarding inquiry (D1.2/D1.3), the basis for specifying criteria for the selection of inquiry activities (D2.1) and support for selecting activities by teachers and/or learners (D1.4), a structure for developing training materials for teachers (D4.1), and a basis for communicating the Ark of Inquiry goals to different stakeholders. It provides all other deliverables with a common reference framework that will help to maintain consistency in the development of the different pillars of the Ark of Inquiry project. As such, the framework will be operationalized and put to test in all subsequent phases of the Ark of Inquiry project. A finalized version of this framework will be presented in D1.5.

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